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TRAINING ENGINEERING:
A PARAMETRIC APPROACH TO COMPUTER-BASED TRAINING DESIGN

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ABSTRACT

Training engineering, a new model for computer-based training (CBT), has been devised and put into use by the Cognitive Engineering Design and Research Team (CEDAR) at Los Alamos National Laboratory. Training engineering is the application of scientific principles to the design, construction, and operation of efficient training systems. Such an approach is necessary because of the level of complexity CBT design and development has reached with the new advanced technologies. Instructional designers are under pressure to implement these new technologies more rapidly than has been required in the past, yet few models have emerged to aid designers in this process. Training engineering is such a model. It provides techniques for design and development that are derived from successful engineering techniques. This paper begins with a discussion of the engineering approach and then applies this approach to training. Examples from prototype CBT projects at Los Alamos are used throughout to illustrate the training engineering concept.

INTRODUCTION

This paper addresses the issue: How can CBT designers and developers keep up with new technologies and provide sound instructional approaches which meet user/project requirements?

This issue will be tackled using the approach called training engineering (see Fig. 1). The engineering approach includes selecting the right tool for the right job. The tools in this case include not only software and hardware but also different design and management approaches.

Over the past 20 years, our knowledge of effective designs for CBT has emerged to the point that we have learned where CBT works and where it does not. We have also learned that computers alone cannot solve existing training or performance problems and that extensive needs assessment and careful design are necessary if CBT programs are to be successfully implemented.

Although our knowledge has increased greatly in the area of CBT design, the hardware and software technologies supporting CBT have advanced at a much greater pace. Now we have relatively low-cost personal computers with the same computing

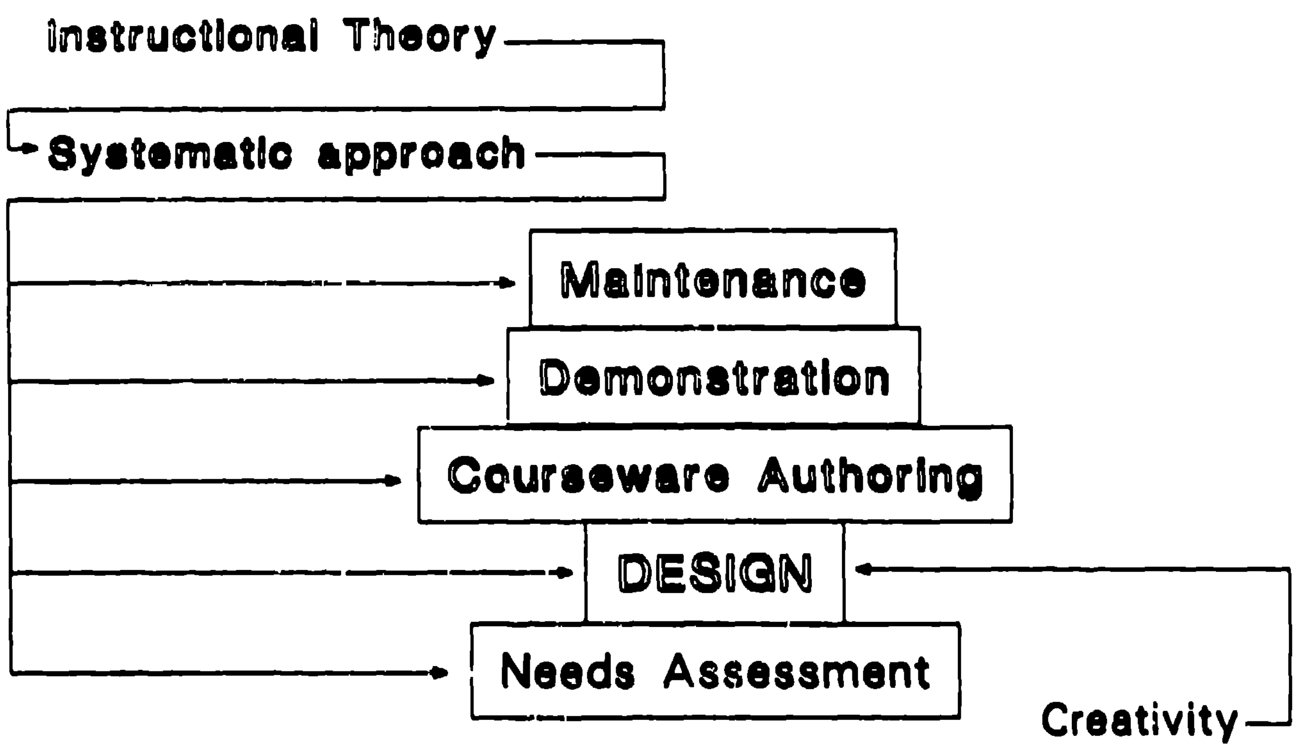

Fig. 1. Computer-Based Training Engineering

power available only from large mainframes two decades ago. We have software tools and systems to facilitate the authoring process, enabling the development of much more sophisticated systems in less time and by less highly trained personnel. We have the capability of storing massive amounts of information which is very rapidly retrievable with a personal computer from storage media such as CD ROM. We can see and hear realistic problem solving scenarios and then work with them in an educational context via interactive videodisc and digital audio. High quality color graphics and animation are able to provide the fidelity of actual video when video is not obtainable or cost effective.

Since the new hardware and software technologies have been so well publicized in the academic and popular press, managers in government and industry are increasingly demanding use of the new technologies. They read the ambitious promises of the new announcements and become convinced that all their training and performance problems can be solved if they only purchase products X, Y, and Z.

Rapid implementation of these hardware and software advancements by designers has resulted in a need to make design and development approaches used for CBT more responsive to the complexity of the task. Two examples of areas requiring new approaches are hardware and software selection and screen design. The selection of hardware and software for a particular development project is now much more complex than in the past, requiring different skills on the part of the staff and often a greater time commitment. For example, there are currently over 400 authoring systems from which to choose.

The challenges in designing an easy-to-learn and easy-to-use system are changing drastically because of the complexity of both function and choice added by the new technologies. Guidelines we have relied upon in the past for screen design are becoming obsolete and are not able to be replaced before a new, more powerful technology emerges. Training engineering should provide a beginning for the evolution of new approaches, which are more responsive to this newfound complexity. This complexity is here to stay, as is CBT; and, therefore, investment into a training engineering outlook should be cost effective from a management standpoint.

Training engineering is both a procedural approach and a philosophy. On the philosophical level, training engineering embraces practicality, pragmatic decision making, building or creating new things, design, utility, and a goal orientation. It includes an attitude that approximation is acceptable initially and precision is achieved through iteration.

This paper begins with a general discussion of the engineering discipline. This is followed by a description of a structural engineer's approach to a construction problem and a training engineer's approach to a CBT problem. The training engineering approach is then summarized.

ABOUT ENGINEERING

The discipline of engineering is a proven one. Some of the greatest human accomplishments have been built by engineers: the Taj-Mahal, the Golden Gate Bridge, the Hoover Dam. These accomplishments reflect the building of extremely complex systems, which needed to be built to last, be on schedule, be built to specifications, and be built to be aesthetically pleasing. CBT today is becoming almost as complex! How were such complex engineering projects accomplished and what can CBT learn from them?

Engineering requires a systematic approach to design, construction, and project management. In the field of engineering, design is based upon proven theories from which the systematic approach is derived. Because of the large number of variables to choose from and the large number of decision points, a systems approach is necessary. Nevertheless, the engineer who exclusively follows a systems approach does not usually succeed. The product of his engineering skills may be structurally sound, but it may be aesthetically displeasing to the human eye.

The systems approach is not new to the field of instruction, but the theoretic basis for CBT was slim until fairly recently. The number of studies that have been performed in the area of computers in instruction is now massive, compared to even a decade ago. Therefore, the basis for the systematic approach is now more sound, enabling us to take the bold step towards an engineering of training. Although CBT design itself is not yet a science, it does have an evolving methodological base from which one can work systematically. The field of architecture is not a science either, yet it is a vital component to engineering projects. Early CBT was either direct conversion of an existing course onto the computer or an art form. Now CBT can be, like engineering, based on a solid foundation and yet also leave room for creativity.

In comparing training engineering to the structural engineering field, one can see the following analogies in terms of roles:

Architect + Structural Engineer + References on Materials = Instructional Designer + Software Developer + Subject Expert

The instructional designer's role, however, encompasses tasks performed by the architect as well as the structural engineer. This role is illustrated more clearly in the section following.

The training engineering approach also puts the training department in a mode of being requirements-driven; it helps avoid the pitfall of choosing to do CBT just to do CBT! An engineer would not choose to build a bridge across a river just because it was an attractive location for a bridge; he/she would require a well-demonstrated need as well as adequate funding. In addition, the bridge would not be built with a pedestrian path and six lanes if it was in a low population area. Yet today, many training departments are implementing CBT on inappropriate applications with hardware and software configurations, which do not match the user needs.

A STRUCTURAL ENGINEER VS. A TRAINING ENGINEER

To define training engineering more clearly, it is useful to go through a scenario of a structural engineering example and then follow it with a scenario of a training engineering example. Table I summarizes the characteristics of each discipline.

TABLE I

STRUCTURAL VS. TRAINING ENGINEERING

	Structural Engineering	Training Engineering
Step 0	ANALYSIS	NEEDS ASSESSMENT
	o sponsor, user interviews	o faculty, student interviews
	o observations	o classroom observations
	o attitude surveys	o attitude surveys
	o cost analyses	o cost, facility analysis
	o forecasting of future needs	o desired future system
	o scheduling requirements	o scheduling requirements
Step 1	DESIGN	INSTRUCTIONAL SYSTEM DESIGN
	o knowledge of materials	o software/hardware info.
	o site, geology information	o info. on possible applications
	o site selection	o application selection
	o analysis of site	o knowledge base study
	o cost estimate	o cost, resource estimate
	o structural design theory,	o instructional design theory
	o approaches to bridge building	o instructional strategies
	o aesthetics	o creative designs
	o proposed time schedule	o proposed time schedule
	o design plan draft	o design document draft
	o review and revisions	o review and revisions
	o model building, sketches added	o rapid prototyping
	o review and revisions	o testing and revisions
	o final design plan	o final design document
	approval	o approval
Step 2	CONSTRUCTION	COURSEWARE AUTHORING
	o manage project	o manage project
	o purchase materials	o purchase hardware
	o hire workers	o add to staff as required
	o assemble team	o divide labor
	o create quality assurance plan	o evaluate plan
	o build bridge	o write courseware
	o provide reports to sponsors	o report to sponsors
	o adjust schedule as needed	o adjust schedule as needed
Step 3	GRAND OPENING	DEMONSTRATION
	o plan for opening	o debug and test
	o coordinate ceremony	o coordinate briefing
	o write script, review	o write briefing, review
Step 4	MAINTENANCE	MAINTENANCE
	o safety check	o ongoing evaluation
	maintenance plan	o maintenance plan

Structural Engineer's Step 0: Analysis

A small town in North Dakota had a bridge which several hundred people travel across to get to work each day. This bridge, built in 1925, was wooden and was judged as structurally unsound. It was critical that the bridge be available at all times for the economy of the town. It was a two-lane bridge, but it did not adequately handle the traffic flow during the morning and evening rush hours. In addition, because of the growth of the town during the past 60 years, pedestrians needed to travel across the bridge to shopping centers and residential areas. The town council ordered and paid for an analytic study to be performed to determine the following:

- The amount of money the town could realistically afford for the the new bridge,
- The requirements of the bridge load today and 10 years from now,
- Residents's attitudes about the new bridge location,
- Town council and chamber of commerce attitudes about desired specification, and

- The desired time scale, to minimize inconvenience.

This information was compiled, recommendations were made, and a report was submitted to the town council for review.

Training Engineer's Step 0: Needs Assessment

A military college determined that it needed to integrate the use of computers in its curriculum. A general, who saw the emerging role of computers in every facet of the armed forces, was concerned about the college's not adequately preparing officers to use computers in the battlefield of the future. Therefore, several members of the faculty started attending short CBT courses, conferences, and expositions to learn more. As more of the faculty members gained expertise in the area of military science, they soon recognized that they needed to consult with some external experts in the area of CBT before they committed significant resources. Consequently, they hired an independent institution to perform a needs assessment.

In the needs assessment, the following was done:

- The education/training goals of the college were identified.
- The current training system was characterized, through observation of classes and interviews with faculty and students.
- Desirable features for the optimal training system were identified through attitude surveys.
- The current and desirable future systems were compared, and the differences in project requirements were described.
- The cost and facility constraints were studied.
- The schedule was reviewed.
- A needs assessment report was prepared and submitted for review and use by the college.

Structural Engineer's Step 1: Design

The town council reviewed the analysis report and accepted its recommendations. Its first recommendation was to go out on bid for an engineering firm to design the bridge and coordinate it's building. These steps were done and the engineers were on board. The head engineer, Joe Fraser, was responsible for producing a design plan for the project. For this, he relied upon his own knowledge of structural engineering, as well as knowledge he has gained from the analytical study and other sources. Specifically, he used information on:

- Characteristics of different building materials
- Current construction costs
- Physical features of different possible sites for the new bridge
- Geological characteristics of the area
- Quality control approaches
- How to build a bridge across this type of river with this type of span and required load
- Maintenance alternatives
- Aesthetically pleasing vs. displeasing bridge designs
- Required time scale for such a project
- Contents of a design plan for a bridge.

Mr. Fraser worked with an architect to pull together the specifications and complete the preliminary design plan. This plan included models and artist's sketches of the bridge. Because Mr. Fraser was a licensed engineer, he had to make certain that his plan reflected his skills and instilled trust in the reader. His plan was reviewed by the engineering firm internally and then revised. It was then taken to the town council for preliminary review, comments were collected, and it was again revised. The plan was then made public to the town, and comments were received at a town meeting. Final revisions were then made.

Training Engineer's Step 1: Instructional System Design

The needs assessment study was reviewed and accepted by the college, and the first recommendation (to assemble a design and development team) was implemented. This team consisted of three people initially, an instructional designer, a hardware expert/software developer, and a subject matter expert (rotational duty). This team was responsible for the first phase of the project, development and testing of one CBT course to replace an existing course for which there was an instructor shortage and a stable subject matter.

The instructional designer, Sara Long, set out to write a design document. For this design document, she relied not only upon her own knowledge of CBT design but also studied the recent literature for new approaches which might suit the needs of this project. She consulted with the hardware/software expert on the optimal configuration to use here and sent this expert out to various expositions to critique current technologies and report back to her. She consulted with the subject matter expert and they systematically selected an application, which would have a high early payoff. The subject matter expert researched the knowledge base for the chosen application and discovered widespread discontent with the current course curriculum; students claimed little of the classroom training was transferable to the field. In her cost/resource estimate and schedule, she factored in an analysis of the knowledge base into the design time. She planned to examine the conceptual model upon which the current instruction was based.

In addition, she examined user requirements for creative interactivity methods, user interfaces and instructional strategies to use in the designing. An instructional strategy is the pedagogical method used in a CBT lesson to aid the student in mastering the performance objective. There are many taxonomies used for instructional strategies. The one she used is by Alessi and Trollip,' in which five different instructional strategies are identified: tutorial, drills, simulations, instructional games, and testing. The instructional strategy chosen is dependent upon the expected outcome. For example, if new knowledge must be acquired by the student, then the tutorial strategy is often chosen. She chose a simulation instructional strategy. Because the need for positive transfer of training was so great for this application, students had the requisite fundamental knowledge in the area and the skills required lend themselves to scenario-driven exercises. The key here, she knew, was to select an instructional strategy which matched user requirements and test it before the actual development began.

Ms. Long then compiled the design document, which contained a preliminary CBT lesson design and various flow diagrams. The design also was built with a separate knowledge base from the user interface, facilitating maintenance. Although there is no licensing of instructional designers, Ms. Long was bound by a moral commitment to produce a design based upon sound instructional principles. Therefore, she made sure that the design document reflected her skills and ethical principles. Following completion of the document, she had the college review the design document and provide feedback. During the review she and the subject matter expert performed an analysis of the knowledge base and incorporated this information along with the reviewer's changes in the next iteration of the design document. She then worked with the hardware/software expert to bring up a prototype very rapidly (two months) on borrowed hardware. Rapid prototyping facilitates the highlighting of desirable features and pinpointing of potential problem areas at an early stage in the project. Research has shown that systems which have been rapidly prototyped result in much lower maintenance costs.[9]

The initial prototype was then tested by the project team, revised, and demonstrated to a few highly interested faculty members. This group included one of the former instructors of the course. These faculty members reviewed the prototype and provided not only subject matter comments but also comments on the user interface, the methods of interactivity chosen, the hardware configuration and the instructional strategy. The simulation instructional strategy received rave reviews, even from the former instructor, as did the use of the borrowed videodisc for scenario presentation. Only a very few parts of the borrowed videodisc were used for the prototype, and a new videodisc needed to be made if this technology was selected. The cost of the design of a simulation, as well as the videodisc, was outlined in the design document. Faculty feedback was discussed by the project team. The hardware used for the prototype was reviewed, and the configuration recommended was revised, deleting the use of digital and audio because of less expensive storage on the videodisc. The borrowed hardware was returned. The design document was revised and submitted for approval.

Structural Engineer's Step 2: Construction

When the design plan was approved by the town council, the engineering firm geared up to begin actual construction. At this point, the design was frozen. They mapped out the project systematically, defining the separate phases and then determining when the phases need to converge on the schedule. The phasing highly affected the workers on the project and the materials at the site at any one time. A project management system was used in determining the schedule, with the major and minor tasks and their milestones clearly identified. The schedule reflected the separate phases and which ones could occur concurrently.

Following the mapping out of the schedule and tasks, the following were performed:

- Materials were purchased.
- A staggered schedule for materials delivery was arranged for to minimize any loss from burglary at the site.
- Workers were interviewed and hired, to match needs at the various times of the project.
- Teams of workers were assembled, with the team foreman oriented concerning the supervisory approach taken by this particular firm.
- The quality control plan was enforced, to ensure that following the project completion the amount of maintenance required was minimal and the degree of safety was maximal.

Actual construction was then performed with Joe Fraser managing the various foremen and ensuring that the project management chart was kept up to date. He kept the town council informed regarding progress relative to the announced schedule. When resource estimates were found to be inaccurate, he reported to the town council and sought advice prior to implementing the change. He performed quality checks following completion of each task.

Training Engineer's Step 2: Courseware Authoring and Production

The design document was approved, and hardware was procured for development and testing. The design was reviewed once again, with the understanding that any changes from here on would probably adversely affect the schedule. Sara Long then laid out the schedule, divided the required labor among the staff, and set milestones for interim demonstrations, testing, in-progress reports, and documentation.

Incorporated in this schedule was work being done in parallel, in particular the programming work being done at the same time as the videodisc production. Since her staff did not currently include script writing and video production expertise, she sought part-time employees for these tasks. When these employees were on board, she had weekly team meetings to keep informed of their work and to orient them concerning her management style. These meetings primarily ensured coordination and creative interaction among the team members and also enabled Sara to write monthly progress reports to the college's upper management.

As Sara had experience in educational evaluation, she also wrote up an evaluation plan. This plan included not only formative evaluation, internal testing and pilot testing during the project but also a summative evaluation plan for the college at the conclusion of the project. The formative evaluation ensured that the software was responsive to the needs of users, as well as being bug free. The summative evaluation was used for decision making. Because the software developer concentrated on development and not testing, she made herself responsible for ensuring that the evaluation plan was followed.

When the building of the courseware began, issues arose on a almost daily basis, which required reviewing the estimated schedule and resources, as well as the basic design. When changes were determined to be in the best interest of the final product, Ms. Long presented those to her management prior to implementation.

Structural Engineer's Step 3: Grand Opening

Once the construction was completed, the bridge was ready to be dedicated prior to use by vehicular and pedestrian traffic. This was the big day that really made the project worth all of the hard work, giving each team member a feeling of personal accomplishment. The engineer coordinated the grand opening with the town council and supervised the workers in performing last minute clean up. Mr. Fraser himself was asked to give the short dedication speech, along with the mayor, prior to the dedication. Therefore, he wrote a script and had it reviewed by his firm, as well as the mayor. This project was visible statewide, as the media had targeted it for attention; and, thus, the engineering firm should attract new business if all went well.

Training Engineer's Step 3: Demonstration

Once the courseware was built and tested internally and with a few target users, it was ready for full-scale demonstration to the college faculty. This project was the first CBT project, setting the tone for the rest of the CBT development effort for the college. Therefore, this demonstration was critical. It was also critical to the job security of the project team. The courseware had to work; the briefing associated with the courseware had to be polished. The entire team was involved in preparations: the instructional designer with writing the briefing and scripting a demonstration that revealed the strongest selling points of the courseware, the hardware/software expert with debugging and preparing the demonstration, and the subject matter expert with assuring that the content of the briefing was appropriate to the target audience and with setting up the briefing.

Structural Engineer's Step 4: Maintenance

An area no one wanted to think about because of its lack of glamour is: Who worries about the bridge after it is done? In fact, a small town like this one did have some civil engineers who did day-to-day maintenance on town buildings and properties, but they had little experience with inspecting and performing upkeep on a bridge. Therefore, as part of the project, a maintenance plan needed to be drawn up. This plan needed to include not only specifications on who performs safety checks and how often but also on how both major and minor repairs were to be handled. This plan needed to be compiled with information from the town council, specifying their preferences. Maintenance was first considered in the design phase, and therefore this step was a matter of implementing a plan tentatively made earlier.

Training Engineer's Step 4: Maintenance

The maintenance of courseware is becoming a hot issue in the CBT field, and the instructional designer was, therefore, aware of the need to provide a maintenance plan along with the final project report. The demonstration was successful, and she would be able to keep her position along with the rest of the team. They would be available to perform maintenance, but they have moved on to another development project and will not have time allocated for maintenance. Consequently, her maintenance plan required the college to devote a subject matter expert, who is computer literate but not a programmer, to perform the maintenance. Because of anticipation of maintenance demands at the design stage, the courseware was built to facilitate rapid updating of the knowledge base. This kind of maintenance is the most common type, and the subject matter expert is very capable of performing the task. The maintenance plan also included recommendations for software revision or debugging. In this case, the original design team would be called upon.

SUMMARY

In reviewing Table I, one can quickly observe how similar structural and training engineering are in practice. Although the title of the major steps may differ somewhat, the subtasks are very similar in function throughout. This fact highlights the use of applying an engineering approach to the development of computer-based training.

In addition to comparing training and structural engineering, one can step back and examine it in light of other approaches. The key to such a comparison is defining the scope of training engineering. Training engineering is not a new instructional design model or a new project management methodology, but rather it is a comprehensive, high-level model for integration of new technologies. It is responsive to the new, added variables with which the instructional designer now has to deal.

Nevertheless, training engineering is also a philosophy. It is a pro-active approach to problem solving that requires working within acceptable risks while striving for creativity. It means using available tools in new ways and recognizes that while one strives for perfection, it is not required for success. It stimulates an urgency to produce tangible products that can be examined and revised. And, finally, it clearly recognizes the responsibility of the engineer to produce sound and enduring products. Table II summarizes these points as five principles to be followed.

TABLE II

FIVE PRINCIPLES FOR IMPLEMENTING TRAINING ENGINEERING

- Be sensitive to design-aesthetics; they are important!
- Use tools and materials available today, not the promise of what is in the laboratory.
- Accept an approximate solution, within safety tolerances, as a good solution.
- Prototype and iterate.
- Remember your responsibility for sound construction.

This paper provides only a beginning to the development of the training engineering concepts, or elaboration of the engineering approach to the various subtasks within needs assessment, design, and authoring is necessary. It does, however, reorient a designer's thinking and enables us to leap to a new level of accomplishment. Instead of researchers' having to develop a meta-level approach to accommodate the new technologies, a proven discipline that maps over well to the education and training field is relied upon to help us make that leap.

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